91602
new 82-10

LEGAL NOTICE

This report was prepared by Ontario Hydro and, while effort has been made to assure the accuracy and applicability of the material contained herein, neither Ontario Hydro nor any person acting on its behalf:

(a) makes any warranty, express or implied with respect to the use of any information, apparatus, method or process disclosed in this report or that such use may not infringe privately owned rights; or

(b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

ontario hydro
research division

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research if Reproduced in Whole or in Part

To: Mr. A.E. Martin
Manager, Retail Delivery System
Retail Customer Division

THE FEASIBILITY OF A MOV ARRESTER AS A VOLTAGE DIVIDER

R.J. Piercy

The feasibility of using a distribution class polymer-clad MOV arrester as the high voltage capacitor in a capacitive voltage divider has been investigated. The proposed device was to be easily installed with a hot stick at any point on an overhead distribution system and there it would record voltage levels in a computer readable memory with an accuracy of ±1%. In the tests of a prototype the best accuracy that could be achieved was ±1.5% with a device that may be difficult to manufacture. Accuracies of ±3% are easily achievable. The total weight of the device will require it to be designed in at least two pieces, to allow installation with a hot stick.

1.0 INTRODUCTION

At the request of Retail Customer Division, the feasibility of using a polymer-clad metal oxide surge arrester as a capacitive voltage divider has been investigated. The intent is to use the divider as part of an electronic recording voltmeter that could be easily installed on the Distribution system.

2.0 DESIGN AND OPERATING PHILOSOPHY

The proposed electronic recording voltmeter would be usable at any point on the overhead primary Distribution system. It would install easily with a hot stick and then record the voltage in a computer readable memory. In addition to monitoring primary voltages, the electronics would be separable from the voltage divider so that it could be used to monitor directly the voltage of 120/240 volt systems.

job	file	date	report no.
14-202-241	815.3	June 1, 1990	90-35-K

3.0 DESIGN PARAMETER REQUIREMENTS

The initial design parameters were specified by Retail Customer Division as follows:

1) accuracy of ±1% of full scale
2) monitor all system voltages up to 16 kV
3) accurate over -40 C to +40 C temperature range
4) 21 day memory
5) system powered or batteries
6) easy to install and remove with live-line tools
7) weatherproof
8) protected against transient voltages
9) optional voltage display attachment
10) maximum weight 7 pounds
11) usable on horizontal and vertical phase conductor configurations
12) neutral lead with recoil assembly
13) adaptable for use in the 90 - 120 volt range
14) adaptable to both meter bases and wall plugs

4.0 PROPOSED DESIGN APPROACH

The design proposed by Retail Customer Division was to use a capacitive voltage divider. This could be implemented by using a metal oxide valve (MOV) surge arrester as a high voltage capacitor. The concept is shown in Figure 1. It involves a polymer-clad MOV arrester installed on the line with a live-line clamp. Below the arrester is a weatherproof box containing the low voltage capacitor and the recording electronics. Below the box is a current limiting fuse and a neutral lead terminated in another live-line clamp. The device would be installed on a phase conductor using a hot stick and the upper live-line clamp. The neutral lead would then be connected to the neutral conductor using a hot stick and the lower live-line clamp.

5.0 SAFETY ASPECTS

The voltage divider would be subject to the full available fault current if it fails. The mode of failure of an MOV in these conditions involves no violent fragmentation, but there is a heavy fault arc, and there can be some shrapnel. Some consideration should therefore be given to fusing the device.

5.1 Fusing

The advantages of incorporating a current limiting fuse into the design of the device are that the hazards of the mode of failure can be eliminated and the size of the neutral lead and the live-line clamps can be reduced. The disadvantages are the increase in the overall weight of the device due to the fuse and its mounting, and the increase in the total length.

If the fuse is omitted there is some probability of the operating personnel being exposed to the hazards of the mode of failure. Since the MOV arrester failure probability is very low, MOV arresters are presently installed without the protection of fuses. However, the probability of the arrester failure may increase if it is installed many times and bounced around in the line truck inbetween installations. It is possible to design the device so that operations' personnel can make a policy on the fusing, or lack of fusing, at their discretion.

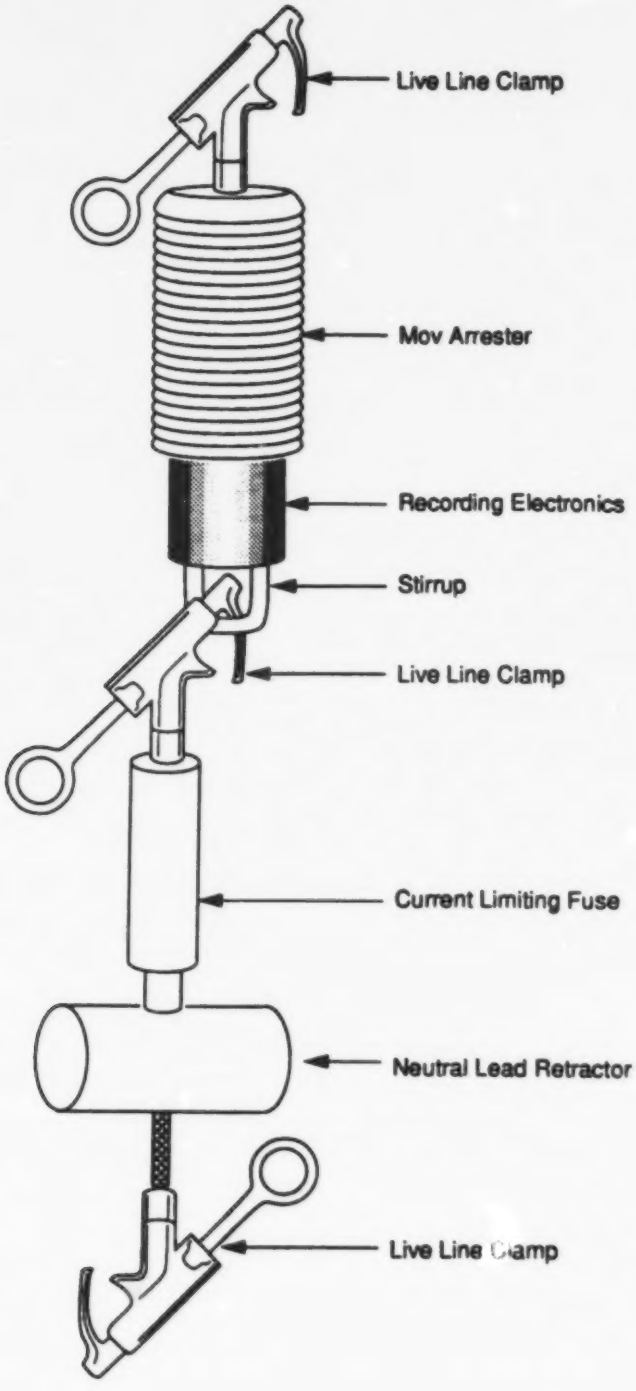

FIGURE 1

PROPOSED ELECTRONIC RECORDING VOLT METER

6.0 PRINCIPAL DESIGN CONSIDERATIONS

The principal design considerations are that the device be sufficiently accurate, light enough to be installed by a hot stick, small enough to be able to hang from the phase conductors, protected from damage by the weather, protected from electrical surges, and that it be possible to manufacture it in large quantities.

6.1 Accuracy

The stated accuracy requirement is ±1% of full scale. This requirement is based on the need to measure voltage drop on the line which should be on the order of 5 to 10% of full scale. Thus an error of 1% of full scale represents an error of 10% to 20% in the quantity of interest.

6.2 Weight

The weight of the device is limited by what can be safely lifted on an 8 foot hot-stick. This limit has been set in the initial design parameters as 7 pounds. This will not be achievable since the MOV arrester itself weighs 7 pounds. The electronics in a weatherproof box would add another 1.5 pounds, each live line clamp adds 0.5 pounds, and a current limiting fuse, if one is used, adds another 2 pounds. The ground lead and clamp add about 2 pounds, or more if a retractor is used on the ground lead. Since the total weight will certainly exceed the 7 pound weight limit it will be necessary to design the divider so that it can be lifted in pieces.

6.3 Length

The overall length of the device is limited by the vertical distance between conductors and the need to maintain the clearances required for safety. This enters into the design of the fuse mounting since connecting a fuse and an arrester in a straight line makes a device approximately one metre long. This would be too long to use on the upper two phase conductors of three-phase conductors arranged one above the other.

6.4 Weatherproofing

Since the device will be exposed to the weather, all the components must be weatherproof. The MOV and the fuse are available in outdoor housings, and weatherproof boxes to hold the electronics are also readily available. If the recording electronics are made to be separable from the divider, then the method of attaching the two weatherproof boxes would have to be carefully designed.

6.5 Surge Protection

Since the device will span between the primary line and the neutral it must be protected from damage by voltage and current surges. The MOV arrester is designed to withstand the surges so the problem is reduced to protecting the low voltage capacitor arm of the divider and the electronics. This can be done using standard techniques.

6.6 Ease of Manufacture

The divider must be designed with some concern for the ease of manufacture. The only component for which this is a major concern is the capacitor in the low voltage leg of the divider. One design option is to use a specially constructed capacitor made by metalizing both sides of a thin slice of metal oxide valve block. A capacitor made in this way will have the same temperature characteristics as the arrester, with a consequent increase in the accuracy. It will also not require surge protection, since the valve blocks are designed to withstand the surge. However, it may not be possible to find a manufacturer able to build these capacitors and willing to do so for the small number that would be required.

7.0 LABORATORY TESTING OF THE MOST ESSENTIAL DESIGN ELEMENTS

The major uncertainty about the suitability of the MOV arrester as a high voltage capacitor was the accuracy that could be expected of the final device. This is dependent on the voltage ratio linearity and temperature stability. Both of these possible sources of error were investigated in the laboratory using both a standard mica capacitor and a specially constructed MOV capacitor as the lower leg of the divider.

7.1 Voltage Ratio Linearity

Figures 2 and 3 show the variation of the voltage ratio with applied voltage. The ratio changes because the capacitance of each MOV element varies with the applied voltage. The data were obtained by changing the voltage in 2 kV steps, allowing the divider to stabilize for five minutes, taking a reading, and then raising the voltage to the next level. The test for the copper plated disk capacitor (Figure 1) was repeated to give an indication of the repeatability of the measurements.

There are two different sources of error evident in Figure 2. The lower points on the graph were from the first data set and illustrate a slight hysteresis. The hysteresis creates a maximum uncertainty of ±0.3% to ±0.7%. The lower value can be used if an operating procedure can be devised that would ensure that the lowest data points, that occurred during the first energization, were not valid for predicting field results.

The other source of error arises from the slope of the graph. Since there is a ±6% tolerance on the line voltage being measured, the slope of the curve implies a ±0.5% tolerance on the divider ratio. This uncertainty could be removed by software processing when the data is read into a computer.

The mica capacitor data on Figure 3 shows only a single measurement. It shows that the rate of change of ratio with voltage would give a maximum uncertainty of ±1.1%, but again this could be removed by processing the data. The hysteresis would probably be similar to graph #1 if the measurements had been repeated.

7.2 Temperature Stability

The effect of ambient temperature on the divider ratio is shown on Figures 4 and 5. The prototype was installed in a controlled temperature chamber and the temperature of the chamber and the arrester were monitored and allowed to stabilize for an hour before a reading was taken.

Figure 4 shows the effect while using a mica capacitor as the bottom leg of the divider. A range of 13% can be seen in the divider ratio as temperature changes from -40 C to +40 C. If standard capacitors like these are used, then the electronic circuitry will have to provide temperature compensation. The repeatability of the data was determined by repeating the test. A range of ±0.6% can be seen on the graph. This is the limit of accuracy even with perfect temperature compensation.

In a practical device the temperature compensation cannot be perfect so there will be some additional error. Since the arrester itself is a totally enclosed device it is impossible to measure its temperature directly. The relationship between the temperature of an accessible point and the actual temperature of the arrester blocks will vary with the environmental conditions, wind, direct sunlight etc. A reasonable guess at the temperature measurement error is ±4C which yields another ±0.6% error in the divider ratio.

STABILITY WITH VOLTAGE VARIATIONS
COPPER PLATED DISK

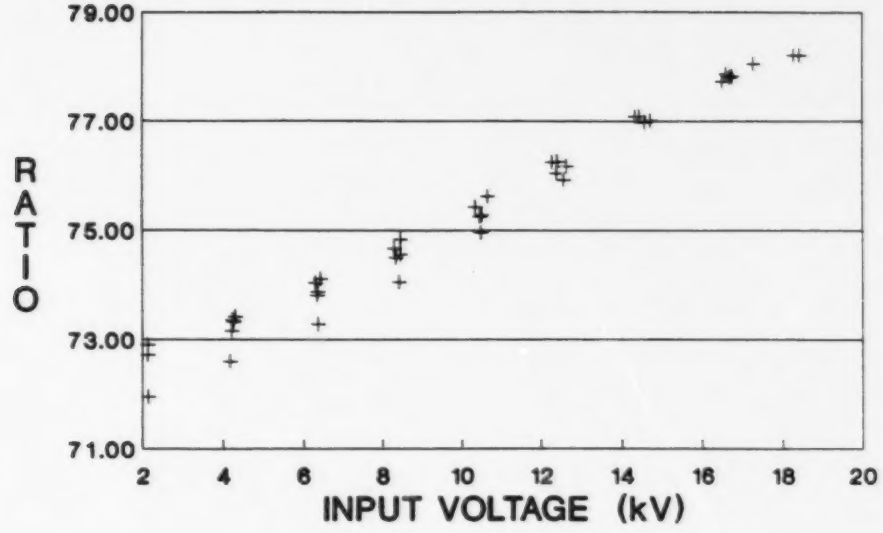

FIGURE 2

STABILITY WITH VOLTAGE VARIATIONS
MICA CAPACITOR

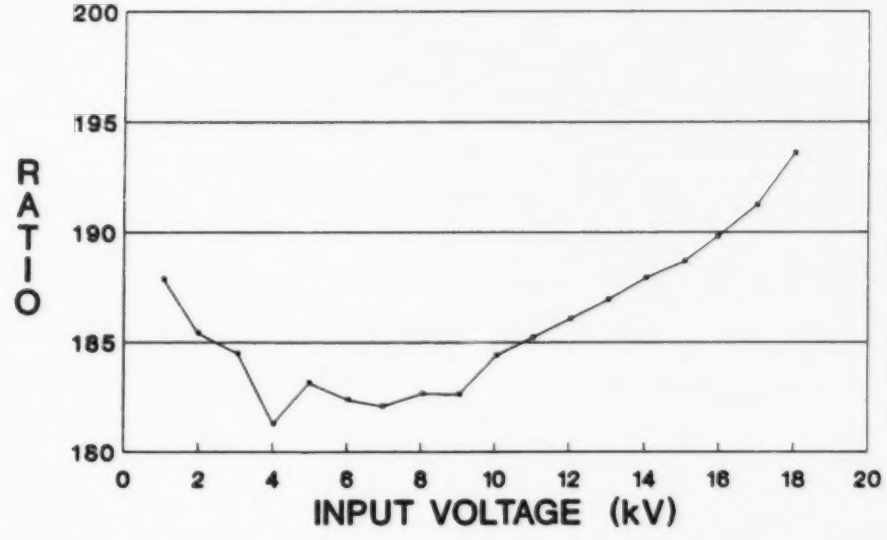

FIGURE 3

Figure 5 shows the same temperature range and the resulting divider ratio range when the copper plated ZnO_2 disk is used as the low voltage capacitor. The range in divider ratio can be seen as ±0.6%. The variation is too random to be narrowed by temperature compensation

7.3 Other Laboratory Tests

In addition to the voltage variation and temperature stability tests the prototype divider was tested to determine its sensitivity to stray capacitances and its long-term stability.

Figure 6 shows that the divider ratio is stable over five hours at constant voltage and temperature to within ±0.06%, which is of the same order of magnitude as the test instruments random errors. No long term instability can be observed.

The effect of stray capacitance was measured by changing the proximity of the divider to the drop leads. There was no effect as long as the drop lead was at least as far away as the length of the arrester. There is a common installation instruction for MOV arresters to ensure they are installed at least two lengths away from drop leads. If this is followed for the ERV, then proximity to drop leads should have no effect on the accuracy.

7.4 Overall Accuracy Estimate

Error Source	ZnO_2 Disk Capacitor	Standard Capacitor
Voltage Divider		
Temperature Repeatability	±0.6%	±1.0%
Voltage Repeatability	±0.7% to ±0.3%	±0.7% to ±0.3%
Temperature Compensation	--------	±0.6%
Ratio Change with Voltage	±0.6% to ±0.1%	±1.9% to ±0.5%
Electronics		
Resistive Divider (Temperature)	±0.2%	----------
Analogue/Digital Conversion	±0.4% to ±0.1%	±0.4% to ±0.1%
Voltage Reference	±0.2%	±0.2%
	±2.7% to ±1.5%	±4.8% to ±2.7%

The lower limits are based on the following assumptions:

- -that operating procedures can eliminate the worst of the voltage hysteresis
- -that the divider ratio is adjusted in software to account for the change with voltage
- -that a 10 bit A/D chip is used

It must be stressed that these are estimates of what accuracy is probably achievable. Only the building and field testing of a prototype will determine the actual accuracy.

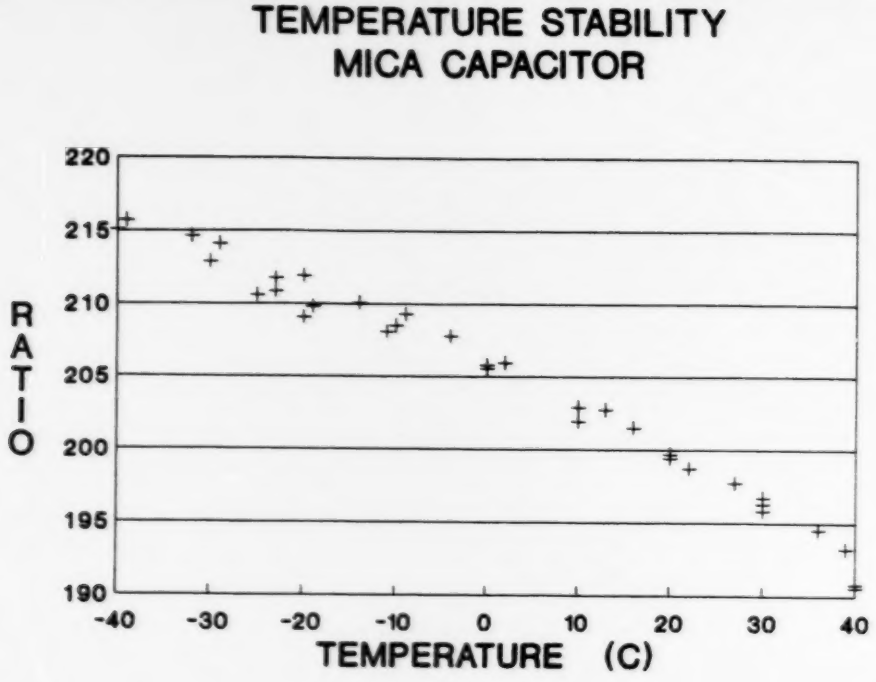

FIGURE 4

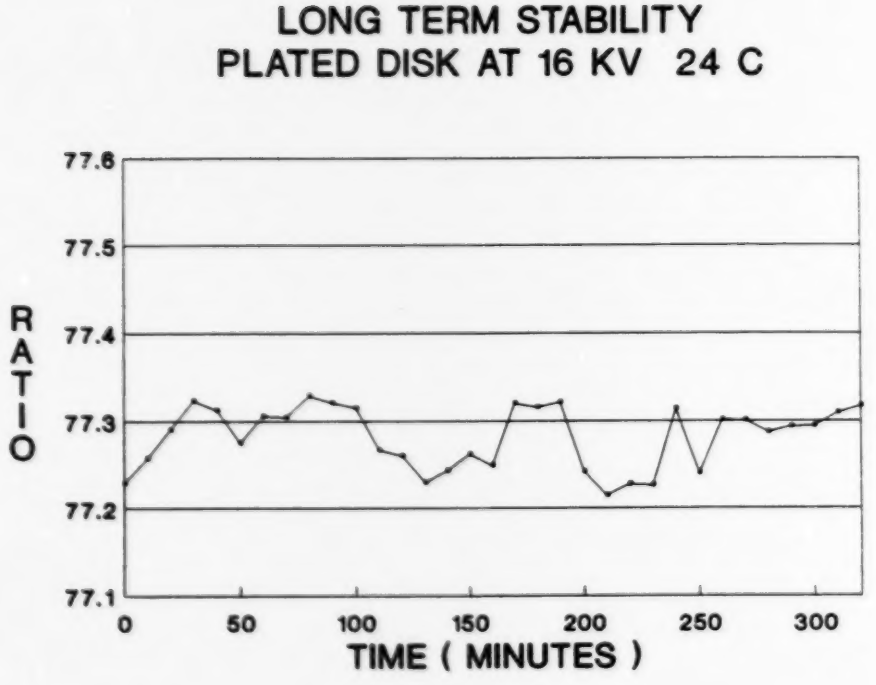

FIGURE 5

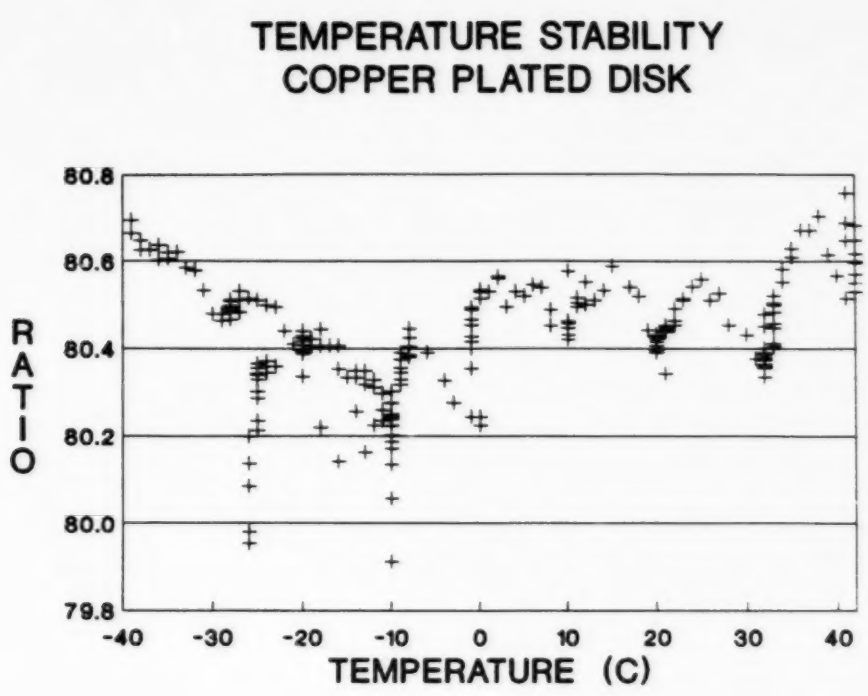

FIGURE 6

8.0 COST ESTIMATES

The cost estimate for the development of an electronic recording voltmeter has been divided into two parts, the divider and the electronics. The divider is estimated to require design, in conjunction with a manufacturer especially if ZnO_2 capacitors are to be made, construction of a few prototypes, and testing first in the laboratory and then in the field. This will require approximately 8 man/months of work at a cost of $100,000.

The cost of developing the electronics depends on the design options chosen. The ERA circuitry could be used with very few changes except that the 2 k X 8 CMOS RAM chips that it uses are being phased out and the 8 bit A/D chip would cause a significant drop in accuracy. To overcome these problems requires a redesign of the circuit. All the design options require the design of a resistive divider circuit for calibration and ranging. The cost of this work would be about $35,000. The standard low voltage capacitor design option requires temperature compensation circuitry. This would require an additional $15,000 for design and testing. The total cost for development of the electronics is $60,000.

The total cost estimate for the development and testing of a working prototype is $160,000. Construction and documentation for the first production prototype of the electronics is estimated to be an additional $20,000 for a total of $190,000.

The cost of the final device is estimated to be about $800. This estimate assumes that the divider would cost about $200 and the electronics would cost about the same as an electronic recording ammeter which sells for $600.

9.0 SUGGESTIONS FOR FURTHER RESEARCH

Since the proposed approach cannot achieve the requested accuracy and ease of use, alternative approaches to providing an electronic recording voltmeter for primary voltages could be considered. In the discussions that led up to this project the other promising approach was to monitor the voltage on the secondary of an existing distribution transformer. The primary voltage could be accurately inferred from the secondary voltage if the transformer loading was also monitored. This could be done in a microprocessor within the ERV housing so that the corrected primary voltage could be displayed immediately.

10.0 CONCLUSIONS

1. The MOV arrester can be used as the high voltage leg of a capacitive divider.
2. The requested accuracy of ±1% is not achievable, but ±3% can be achieved and the lower limit of ±1.5% may be possible.
3. The total weight of the divider would be too large to be installed with a hot stick. The problem could be overcome by attaching the device to the power line in two pieces.
4. The development would require at least one year and cost about $190,000.

Approved:

A.F. Baljet
Manager
Electrical Research Department

Submitted:

R.J. Piercy
Engineer
Electrical Testing & Development Section

RJP:TMAC

APPENDIX A

Design Details

During the feasibility study, there were several elements of the design that were discussed that do not relate directly to the feasibility of using a MOV arrester as a voltage divider, but are things that should be kept in mind if an electronic recording voltmeter is developed along the lines sketched out in this report.

Arrester Disconnector

One of these design details is whether an arrester disconnector will be required in the design, and whether it could in some way take the place of a fuse. If a fuse is not included in the design, then an arrester disconnector will be required. The MOV arrester is designed to be non-fragmenting only on the initial fault current and not on the subsequent faults as a recloser operates. The disconnector is required to isolate the arrester if it fails. If a fuse is included in the design it will serve to isolate a failed arrester. The operation of the disconnector is not fast enough to offer any protection like that provided by a fuse. It would not decrease the hazard on the initial fault.

Specially Fabricated Zinc Oxide Capacitors

There are several detailed considerations around the decision to use a specially constructed MOV capacitor. During the production of the test samples, conventional metal spraying techniques did not achieve a good bond between the metal and the zinc oxide, even if special bonding agents were used. It is possible that the thermal shock of the hot metal hitting the ceramic material produced cracks under the surface of the ceramic. This might be avoided by spraying only small amounts at a time. The test samples were finally produced by using an evaporation in a vacuum technique where the metal temperatures are lower.

There is a potential long term problem with the zinc oxide capacitors. Zinc oxide is known to be affected by diffusion of other materials into or out of it's surfaces. If the copper that plates the surfaces diffuses into the zinc oxide over time, then the capacitance could change and alter the calibration of the divider.

Rather than making up a special zinc oxide capacitor it may be possible to use a small regular production valve block. This will have much less capacitance and therefore produce a higher voltage but a resistive divider could be used to reduce it before the signal is sent to the electronics. The potential problem with this approach is that the smaller blocks thermal characteristics may not match those of a larger block due to the differences in the way they cool after sintering.

Temperature Compensation for Regular Low Voltage Capacitors

If a regular low voltage capacitor is used in the low voltage leg of the divider, then temperature compensation will be required. It can be achieved in two ways, either a temperature probe is used to determine the temperature and then the proper divider ratio for that temperature is looked up in a table stored in ROM, or else the voltage signal is sent through an electronic circuit that has a temperature characteristic of its own that matches the divider temperature characteristic. The first option is easier to implement and can be made more accurate.

Live Line Clamps

The type of live line clamp required to attach the divider to the line depends on the mounting arrangement on the line. If a stirrup is used on the line then a small live line clamp can be used on the divider with a subsequent saving in weight. However, it would seem to be advantageous to be able to apply the arrester at any point on the line without the need to install a stirrup. In order to safely apply a live-line clamp directly to the conductor a larger and heavier clamp is required.

Removable Electronics

It has been suggested that the electronics box be made removable so that it can be used to monitor 120 V systems. Removable electronics would also make the device easier to use since the heavy divider could be left on the truck when the device is brought in to read the data onto a computer. This could be an important saving when three phase installations are used. However, making the electronics removable makes the design of the weatherproof housing more difficult. It also allows the possibility of mixing up which electronic package goes with which divider. This is a problem because, to get the greatest accuracy, the electronics must be calibrated to each individual divider. The requirement to monitor 120 volt systems might be removed since there are already devices on the market to do this, notably an adapter to the electronic recording ammeter already in use in Ontario Hydro.